Development of High-Sensitivity Fluxgate Magnetometer Using Single-Crystal Yttrium-Iron Garnet Thick Film as the Core Material

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LONG-TERM GOALS

Traditionally, a fluxgate sensor is made of amorphous metallic magnetic ribbons by which the second-order harmonics is characterized in relation to an imposed dc field. Resolution of the sensor device is limited by Barkhausen jumps generated in the core region. In contrast to the conventional approach we propose to perform fluxgate operation coherently involving detection of the generated harmonics of all orders, or to apply the matched filter theory invoking autocorrelation of the signal-waveform itself. As such, noise influence is minimized, since noise can only add to the detection scheme incoherently at each individual harmonic frequencies. In order to achieve this goal we choose to work with insulator cores, such as single-crystal yttrium-iron-garnet (YIG) thick films. Due to the nearly perfect crystalline structure of YIG films we expect magnetization processes taking place on the film plane arise, instead of domain-wall motion, mainly from magnetization-vector rotation, since nucleation of reversal domains are energetically not favorable. As such, Barkhausen noise is reduced, resulting in a high sensitivity of the fluxgate device. Our long-term goals are to fabricate efficient fluxgate sensors using YIG films as the core material providing the following advantages: reliability, ruggedness, and economy. Most importantly, the improved detection scheme allows the fluxgate magnetometer to be applied to dynamic signals, not necessarily to be restricted to the traditional usage detecting static or quasi-static magnetic signals. For example, we anticipate sensitive magnetic recording heads will be made of fluxgate sensors in the future to characterize digital signals flowing at high repetition rates.

OBJECTIVES

The objectives of the research are to develop a new class of fluxgate magnetometers using insulator YIG as the core material measuring and analyzing the gated signal in the coherent scheme. As such, noise content is reduced and the sensitivity of the device increased. We expect that our research products can ultimately compete with the more complicated and costly SQUID fluxmeter operating at liquid helium temperatures. New usage of a fluxgate device is also anticipated, detecting dynamic magnetic signals with high resolution at high speeds.

APPROACH

We first fabricate prototype fluxgate magnetometers using insulator YIG films as the sensor-core material. High-order harmonics are then measured and included in the detection scheme in a coherent manner so as to increase the signal-to-noise ratio. Alternatively, signal autocorrelation processors, or matched filters, are employed so that high-order coherent detection is performed in digital form. Fluxgate performance is compared and analyzed based on different core materials, including metals, metallic glasses, and insulators. The prototype device will be further miniaturized in the future, improving temperature stabilization, reducing power requirement, and simplifying software manipulation to allow for optimal performance. The prototype will include all necessary electronics miniaturization, improved ruggedness, reliability in performance, and lower fabrication costs. New applications, such as fast magnetic recording heads, will be explored, utilizing fluxgate operation in reading the stored digital data in a magnetic medium, competing with the traditional sensors such as induction heads or magnetoresistive heads currently available in the market.

WORK COMPLETED

Fluxgate magnetometer with a ring-shaped insulator core containing single-crystal yttrium-iron-garnet (YIG) films has been fabricated. The core was of an inner diameter 0.4", an outer diameter 0.65", and a thickness 0.027". The core consisted of two layers of crystal YIG thick films of nominal thickness 100 μm grown on both sides of a GGG (gallium gadolinium garnet) substrate along the <111> direction. Primary coil contained 378 turns of AWG-34 wire wound around the core periphery capable of generating an axial magnetic field of 146 Oe per ampere of the drive current, i_p. The core plus the primary-coil assembly was inserted in the hollow duct of the secondary-coil support made of polycarbonate. The inner dimension of the support was 0.1" × 0.675" × 0.8" and the secondary coil consisted of 240 turns of lacquered copper wire AWG 34 capable of generating a magnetic field of 150 Oe per ampere of the secondary current, i_s. The fluxgate geometry is shown in Fig.1A.

For the purpose of comparison a second fluxgate magnetometer containing an amorphous-metal core was also fabricated, as shown in Fig.1B. The core consisted of 2 wraps of As-Cast Metglas 2705M foil (Honeywell, Morristown, NJ) characterized by the following parameters: thickness 0.001", saturation magnetization 7700 G, coercive force 0.015 Oe, initial permeability 290000, conductivity 136 μΩ-cm, Curie Temperature 365 ^{o}C, and saturation magnetostriction << 1 ppm. The Metglas foil was cut into a strip 0.5" wide and 2.35" long, wrapping across the supports for two identical halves of the primary coil stacking together showing symmetry. Each half of the primary coil contained 241 turns of lacquered copper wire AWG 34 capable of generating an axial magnetic field of 151 Oe per ampere of the primary current, i_p. The supports of the primary coil were made of polycarbonate, showing hollow ducts of dimension 0.05" × 0.55" × 0.8", allowing the Metglas foil to pass through and to wrap around. Similar to a ring-shaped core, the amorphous-metal core also implies the flux-closure condition so as to ensure a small inductance of the primary coil. That is, the self-inductance of one half the primary coil is nearly canceled by the mutual inductance of the other half, and vice versa. Among other considerations, the flux-closure condition is favorably held by a ring-shaped core employed in a fluxgate magnetometer.

The amorphous-metal core plus the primary-coil assembly was then inserted in the hollow duct of the secondary-coil support made of polycarbonate. The inner dimension of the support was 0.3" × 0.8" × 1" and the secondary coil consisted of 300 turns of lacquered copper wire AWG 34 capable of generating a magnetic field of 150 Oe per ampere of the secondary current, i_s. Both of the ring-shaped insulator YIG core and the wrapped amorphous-metal-foil core, together with their respective pickup, or secondary, coils, were inserted in a common compensation coil performing fluxgate operation. The common compensation coil consisted of 276 turns of AWG 26 wire winding across a polycarbonate bobbin of diameter 1.5" and length 2.5", capable of generating an axial magnetic field, H_0, of 58 Oe per ampere of the compensation current, I_0. The bobbin had a hollow rectangular duct allowing the two cores to sit in, YIG and Metglas, to be affixed to the center of the bobbin by two Teflon screws. The compensation coil, together with the drive and the pickup coils with YIG or Metglas core sat in, was inserted in a shielded chamber consisting of 6 mu-metal sheets wherein fluxgate operation is induced and measured. The drive current was applied at 20 KHz capable of magnetizing the core materials passing saturation.